

MuCool LH₂ pump test report

Fermilab/BD/Cryogenic

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1 Introduction

A preliminary feasibility study of the MuCool project is conducted at Fermilab with one liquid hydrogen (LH₂) absorber at a new MuCool Test Area (MTA) [1-3]. A close loop of LH₂ subcooled at 17 K and 1.2 atm, will be circulated by a mechanical pump at a flow rate up to 0.55 kg/s. The proposed LH₂ pump was designed and built by Caltech as a spare pump for the SAMPLE experiment [4].

Since LH₂ flows in the opposite direction for SAMPLE and MTA, the LH₂ pump capacity on reverse mode needs to be compared to its design capacity. Hence, the MuCool LH₂ pump flow direction was tested using water.

2 Purpose

Figure 1 illustrates the implementation of the LH₂ pump in the MuCool Test Area (MTA). A more detailed description is available [1]. The hydrogen loop consists of the liquid hydrogen absorber, He/H₂ heat exchanger, LH₂ pump, transfer lines, safety devices and instrumentation. For a better thermo hydraulic solution, the LH₂ pump needs to circulate LH₂ flow from the lower part of the absorber to the upper part.

The LH₂ pump motor needs to be sited at the vertical of the pump and outside the magnet bore. The SAMPLE LH₂ pump that we intend to use at MTA was designed to flow hydrogen in the opposite direction [4]. Thus, we need to validate that the pump can work in the reverse mode and we need to compare its capacity in reverse and design (forward) modes.

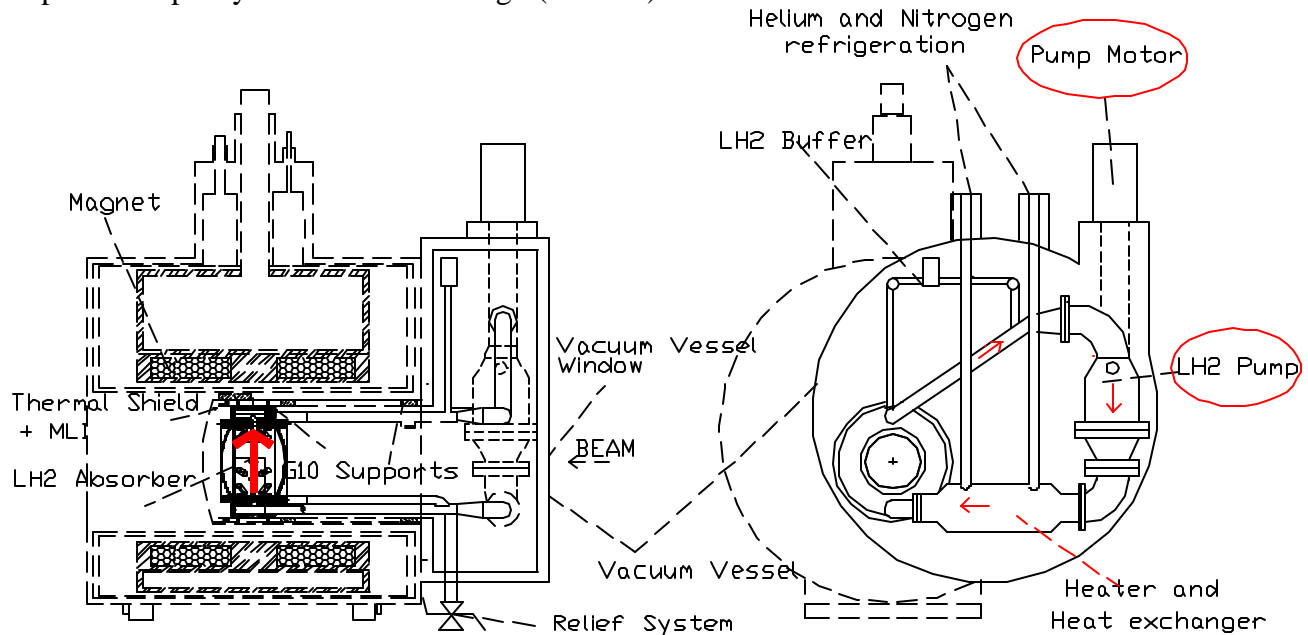


Figure 1: Conceptual design of the MuCool Test Area cryo-system

3 Description of the LH₂ pump

The SAMPLE/MuCool LH₂ pump is a 20 cm long per 18 cm of diameter cylinder. Figure 2 shows the implementation of the LH₂ pump in the SAMPLE experiment that operated up to 2001 at Bates[4]. The LH₂ pump motor was located at room temperature and encapsulated in a vessel sealed outside the cryostat vacuum vessel. This vessel is filled with gaseous hydrogen and exchanges by thermal conduction with the ambient the heat generated by a pump motor.

Figure 3 shows the pump design. Two impellers blades are used to accelerate the flow, three stators are used to straighten the flow and two cones to reduce the impedance of the flow. The material used for impellers and stators is Al 6061 T6. Photo 1 and Photo 2 show the inner parts of the LH₂ pump and the outer shell. The LH₂ pump motor drives the pumps via $\frac{3}{4}$ inch diameter stainless steel shafts connecting the impellers to the LH₂ pump motor. A stainless steel outer shell surrounds the pump and the shafts. This outer shell permits us to insulate the hydrogen space from the vacuum space inside the cryostat and from the ambient outside the cryostat. In order to limit the heat load to the LH₂ loop, foam fills the space between the shafts and the outer shell. LH₂ will vaporize from the LH₂ pump through the shafts and to the LH₂ pump motor. The heat load from the LH₂ pump motor vessel at room temperature and the LH₂ pump at 17 K is estimated to less than 100 Watt [4].

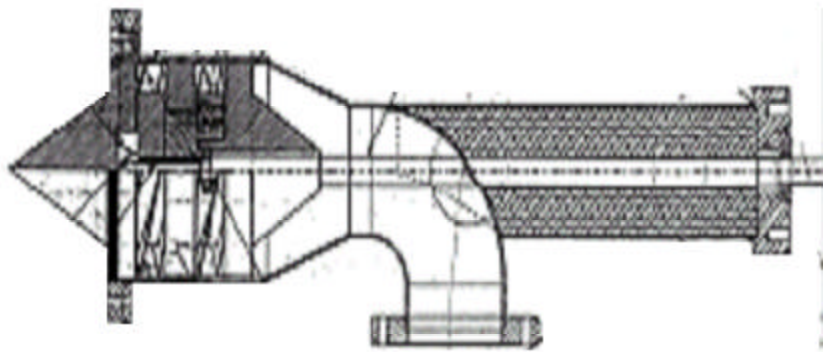
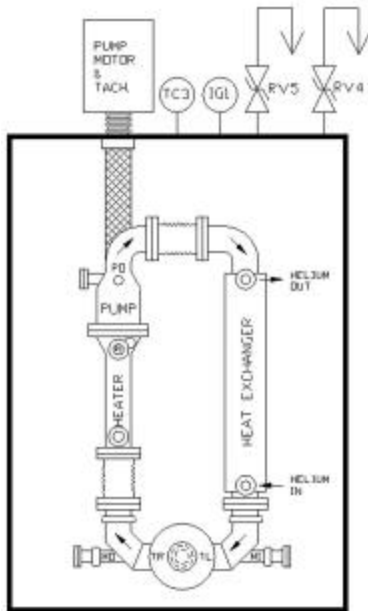


Figure 2: Schematic of the SAMPLE experiment Figure 3: Detail of the LH₂ SAMPLE pump



Photo 1: View of the 2 impellers and stator

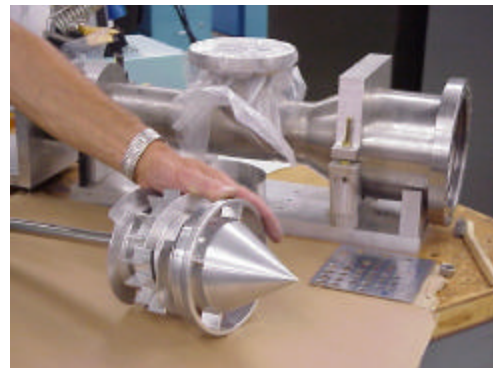


Photo 2: View of the inner part of the pump with its outer shell.

4 Description of the test

4.1 Purpose

The purposes of the test were 1) to compare the pumping capacity in forward and reverse mode, and 2) to measure the influence of the density change by varying the temperatures of the fluid.

This test did not intend to characterize the LH₂ pump operating at LH₂ conditions, but rather to validate the operation of the LH₂ pump in reverse mode. Thus, we use water as the fluid to ease the test. If we can prove that the pump mode are equivalent, then we can use the existing characteristics provided by SAMPLE team (see section 5).

We measure the mass-flow for the purpose of comparing the LH₂ pump capacity. Different configurations of flow directions and water flow temperatures are studied.

Figure 4 shows the schematic of the MuCool LH₂ pump test set-up. We simulate the flow of LH₂ by circulating a flow of water in a close loop. The LH₂ pump circulates water in and out of an open tank. The close loop is composed of the LH₂ pump in series with the flow meter. A heater installes at the bottom of the water vessel controls the water temperature.

For this set-up, the LH₂ pump motor shaft connects the LH₂ pump shaft by means of a flexible coupling made out of Hytrel material (or Buna-N).

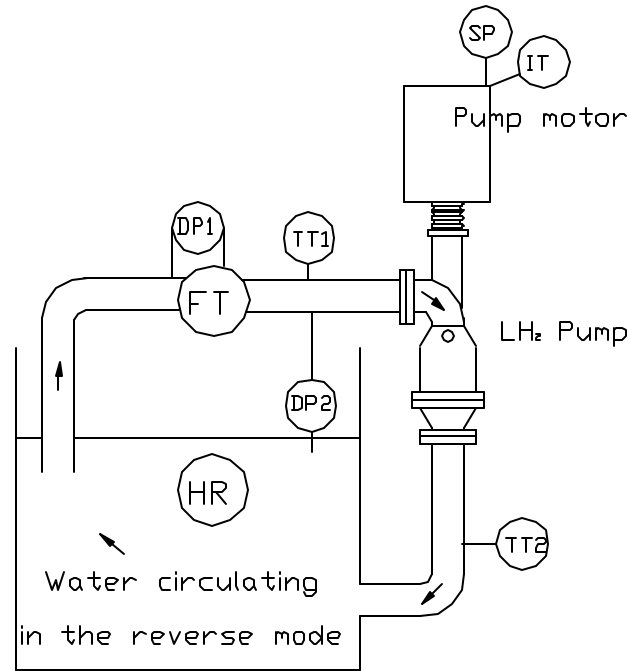


Figure 4: Schematic of the MuCool LH₂ pump test set-up

Photo 3 shows the test set-up and the location of the different components and instrumentations. The LH₂ pump motor is relatively heavy (~60 Kg) and is secured by dedicated supports. The LH₂ pump motor is sitting at the vertical top end of the LH₂ pump and outside of the water tank to avoid electrical incident. A Plexiglass cover protects the water tank.

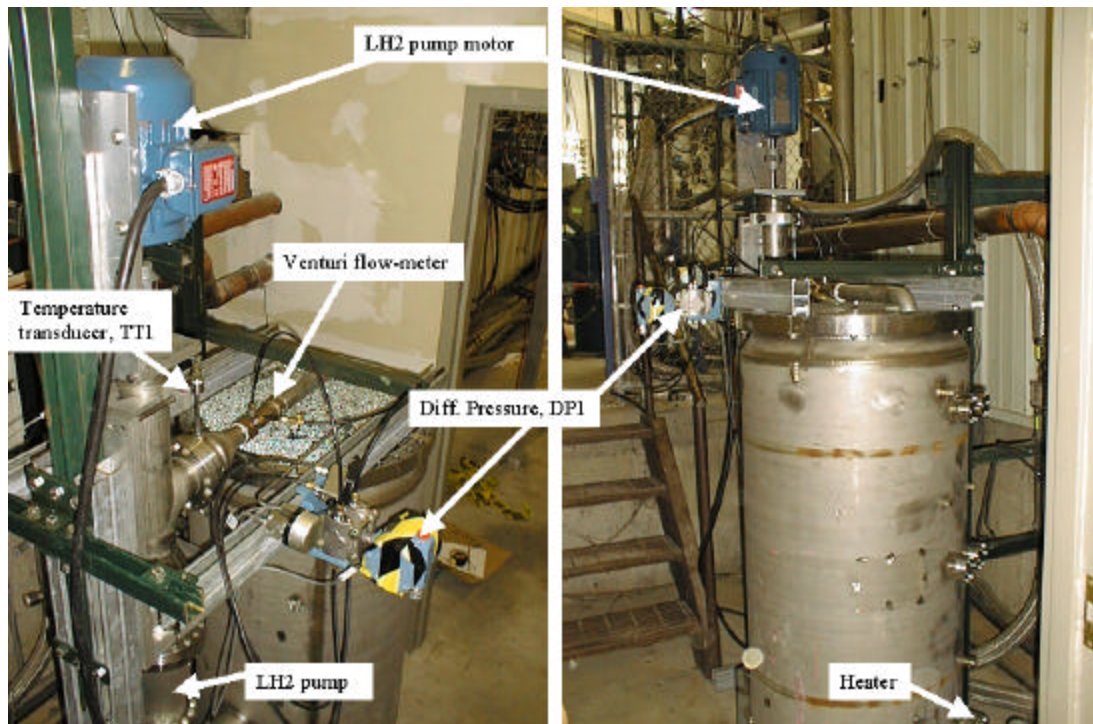


Photo 3 : View of the MuCool LH₂ pump test set-up at ER

4.2 Instrumentation, control and acquisition

Flowmeter, heater, temperature sensors and pressure transducers are used in addition to the controllable motor. Table 1 shows the instrumentation list and accuracy of the devices.

- The flowmeter is Venturi type. The flow is determined by measuring the difference of pressure across the Venturi flowmeter. This pressure difference is measured with a 0-10 psid (Rosemount) pressure transducer.
- The direction of the flow is also recorded with a second differential pressure transducer (Setra: 0-5 psid) measuring the pressure difference between the water bath and the inlet of the flowmeter.
- LM135 type temperature sensors, TT1 and TT2, measure the water temperature in two points of the water loop. An infrared thermometer is used to confirm the temperature and the homogeneity of the bath.
- A 1KW heater Chromalox, controlled the temperature of the water flow from 70 to 250 degree F.
- A Yaskawa motor model GPD515/G5 is used to control the LH₂ pump motor speed in both forward and reverse direction. A 2.5 HP is used to drive the LH₂ pump. The speed, SP, and current, IT, of the motor is measured.

The motor frequency and speed is controllable via Tevatron controls system used for cryogenic applications. This existing control system is adapted to provide the possibility to operate the motor in both forward and reverse mode. The speed of the pump is controllable by varying the frequency. The maximum speed of the motor that we used is 1200 RPM, equivalent to 41.7 Hz.

The sampling time for all other data is of order of 0.5 seconds.

Table 1: List of Instrumentation

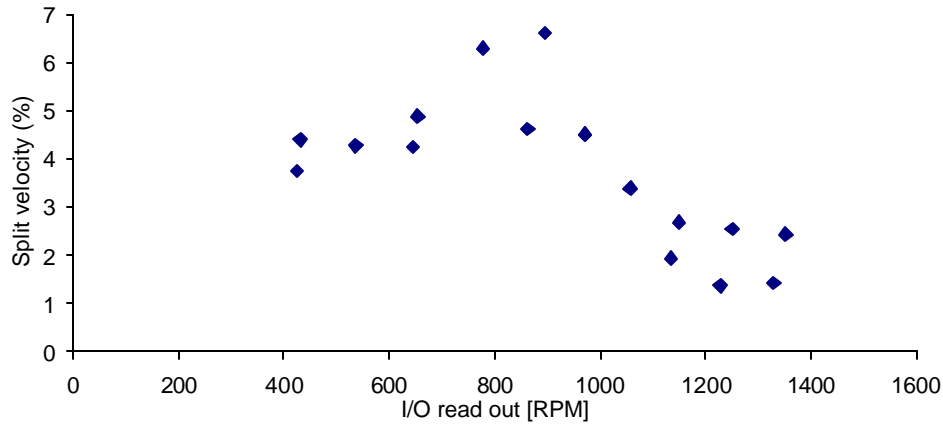
Instrumentation	Item	Supplier	Accuracy
Heater	HR	Chromalox	1%
Flow meter	FT	Venturi	1%
Differential Pressure	DP1	Rosemount	0.20%
Differential Pressure	DP2	Setra	0.14%
Temperature sensor	TT1	LM135	1%
Temperature sensor	TT2	LM135	1%
Motor Speed	SP	Yaskawa	0%
Motor Current	IT	Yaskawa	0.20%

5 Experimental results

5.1 Commissioning

LH₂ pump motor speed is especially studied. Error analysis is driven by the measurement of the slip velocity of the LH₂ pump motor shaft. This slip velocity is mainly due to the friction between the impellers and the water. The read-out frequency, f_{ro} , was compared to the real frequency of the shaft, f_r , by using a stroboscope light. Figure 5 shows the slip velocity versus the read-out frequency. The slip velocity is expressed in percent as the difference between the true velocity and the measured velocity, normalized by the true velocity:

$$\text{slip velocity (\%)} = \frac{(f_{ro} - f_r)}{f_{ro}} * 100$$

Figure 5: Slip velocity of the LH₂ pump motor to the water bath.

Flow temperature change (or the density change) in the 70-250 degF range do not influence the slip velocity in a significant manner.

A maximum of 7 % of slip velocity (or error) is measured between the input frequencies (or read-out) and the one measured with the stroboscope. The slip velocity vary when the frequency increases and has a maximum around 900 RPM. Therefore we use an error margin of +/-3.5% on the measurement of the motor speed.

5.2 Test procedure

The test consists in comparing the flow of water for different configurations of temperatures and water flow directions. For each configuration, conditions are determined by varying the speed of the LH₂ pump motor. The same sequence of 12 conditions is repeated for each configuration. Eight configurations are tested including redundant configurations for both forward and reverse modes. Figure 6 shows the successive sequences reproduced for the 8 different configurations. It illustrates the steps due to the successive increase of LH₂ pump velocity and the time necessary to perform the measurements at stabilized condition. Pressures, temperatures, motor speed and current are measured for each condition and with stabilization of flow direction and temperatures. The change of conditions occurs about every 8 minutes, providing enough data for redundancy analysis and reducing the error due to the frequency change fine-tuning. Ensemble averages of the data are determined for each motor speed condition.

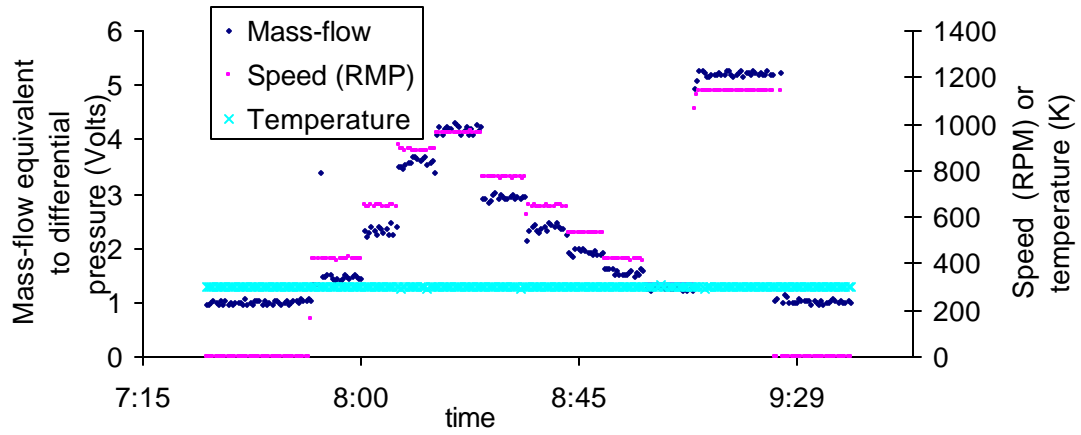


Figure 6: Sequence of data

The value of the mass-flow can be determined on the ensemble average of the pressure difference, DP1. Then the value of the mass-flow is deduced from the Venturi flow-meter calibration.

In a second step the data can be expressed as a function of the speed of the LH₂ pump motor. Figure 7 shows the converted mass flow and the temperatures versus the LH2 pump motor. The error bars on the data measurements are deduced from the accuracy of the data and from the distribution on Figure7.

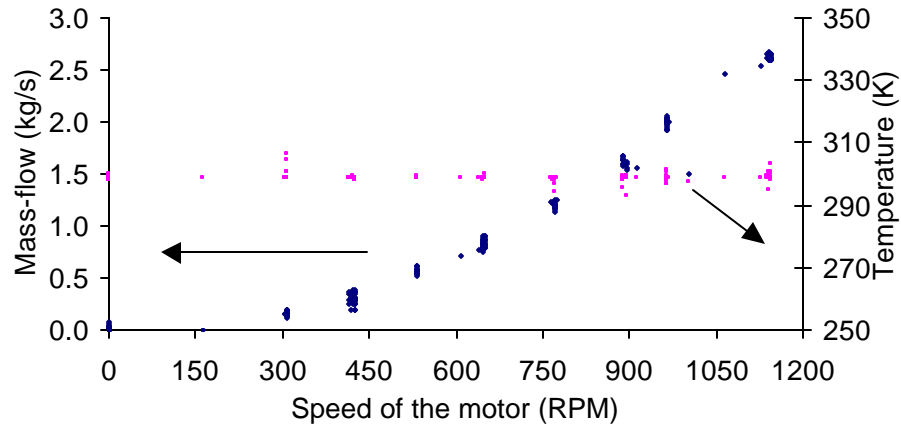


Figure 7: Mass flow and temperature for the room temperature in reverse mode.

5.3 Results & Analysis

Three water flow temperatures, reverse and forward mode of the so-called LH₂ pump have been studied. Figure 8 shows the data for the entire test run with the error margins. Six configurations are displayed including redundant cases.

The error bar for the speed of the LH₂ pump motor is shown for the main configuration (reverse mode and room temperature). The error bar for the speed of the LH₂ pump motor is the slip velocity. An average of 5 % is used. The error bar for the mass flow measurement is estimated to $\pm 2\%$. This error takes into account the accuracies of the differential pressure measurement, data acquisition, data processing and conversion error.

Therefore measurements of the water mass-flow appears to be less than 5% lower in the reverse mode then in the forward mode for which the LH₂ pump has been designed. The repeatability of the measurements is good in the sense that values are within the error margins. The standard deviation for the measurements of the mass flow is of the order of 0.02.

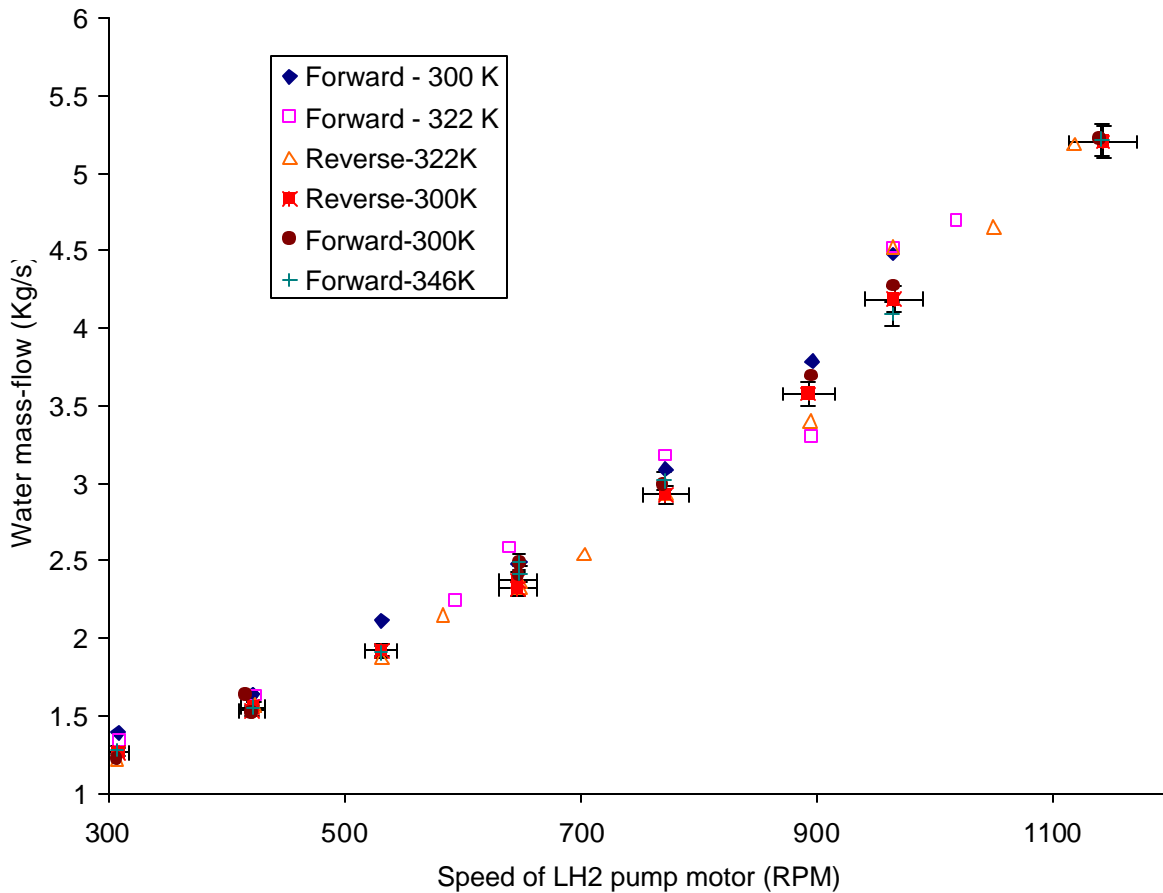


Figure 8: Comparison of the all data.

No influence of the density and temperature is observed whereas a net dependence should be observable for larger temperatures ranges. Without this correlation, no extrapolation to the LH₂ conditions can be deduced from the present measurements. Nevertheless the main objective of the test is met since we validated that the pump can operate in reverse or forward mode providing the same

capacity. The characteristic of the ump can therefore be deduced from the SAMPLE measurements. The use of the LH₂ pump at MTA will be similar to its use at SAMPLE. Therefore we can recall the capacity of the SAMPLE LH₂ pump [4]. Figure 9 shows the pressure drop and the pump speed as a function of the mass-flow. The mass-flow was determined by the temperature rise across a known power source. The pressure drop across the pump was measured at LH₂ temperature and 2 atm. The pressure drop across the pump would be 0.3 psid for a 400 g/s mass-flow of LH₂ and it is of order of 0.048 psid for a mass-flow of 100 g/s.

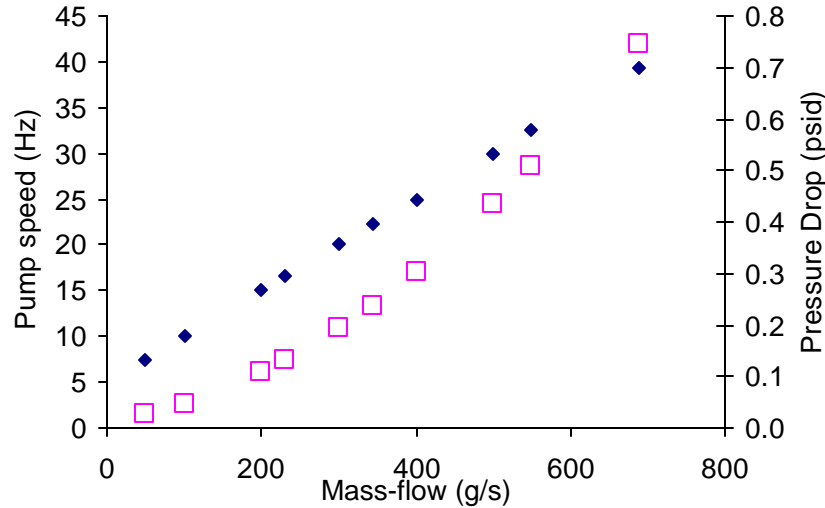


Figure 9: Capacity of the LH₂ pump

6 Conclusion

A LH₂ pump designed by Caltech for the SAMPLE experiment was tested with water flow at normal conditions. The purpose of the test was to prove the feasibility of the LH₂ pump operating in a mode reversed from its design flow. Less than 5 % of capacity difference was measured if pump operates in reverse or forward mode. The error bar being 5 %, we can conclude that both modes are equivalent. Hence we can deduce the characteristics of the pump that we intend to use at MuCool Test Area (MTA). The influence of the density change or temperature change was not proved to be relevant in the given range.

The LH₂ pump motor will run at MTA in the reverse mode. For security reason we will not exceeding 450 g/s. In reality, the LH₂ mass-flow requested at MTA should be less then 100 g/s, since the physics requirements are less strict then at SAMPLE: for a specification of 150-Watt muon/proton beam, the LH₂ density change at MTA can be up to 5 %.

References

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